European Study on Heat Recovery in Non-residential Buildings

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The HR (heat recovery) is generally assessed very positively from a business and economic point of view.

In order to demonstrate this development, a study will evaluate around 5,000 design data elements. First, the designs are evaluated with the question of how the key efficiency characteristics of the HR have changed throughout the course of the years 2014 to 2017. Afterwards, all relevant design files are subjected to an economic efficiency calculation under defined conditions, in order to determine the potential for a multidimensional optimization. Furthermore, the impact of the EU 1253/2014 benchmarks from 2020 onwards will also be examined. The influence of the climate is thereby also taken into account by examining three European sites (North-South view). At the same time, the influence of the run time of the systems will be calculated.

Ultimately, the analyses will provide recommendations for the future design of the Eco-design regulation.

Field study on the development of heat recovery (HR)

Heat recovery systems have been used for years to reduce the required primary thermal energy demand in HVAC units and systems non-residential buildings.

Despite this positive development, the question arises more and more frequently as to whether these provisions of the Eco-design regulation EU 1253/2014[1] actually represent an optimum of the HR system in the microeconomic or national macroeconomic sense.

1 Commission Regulation (EU) No 1253/2014 from July 7, 2014 regarding the implementation of the Directive 2009/125/EC of the European Parliament and the Council regarding the requirements for the environmentally compatible design of ventilation systems. Published on 25.11.2014.

In order to answer this question, a total of approx. 4,800 air handling unit (AHU) designs from 2014 up to and including the first half of 2018 were evaluated according to economic aspects. These are actual designs that were carried out with TÜV-certified design software on the basis of specific tenders in a broad range of projects. Each device is therefore based on a real project with actual performance requirements that are in line with the market and therefore representative for the market of AHU´s used in non-residential buildings.

Each HVAC unit with HR was subjected to a quasi-dynamic economic efficiency calculation using a batch generator (software bot). Two usage cases were thereby investigated. On the one hand, a design with initial values, i. e. predefined basic conditions that are to apply equally to all designs, and on the other hand, a design with file values, i. e. the data that was already selected in the concrete design for the respective project during the original design.

When performing a consideration with initial values, the designs were also only evaluated for an identical location, while file values took into account the actual location that was already selected at that stage of the project.

Three locations were selected to take into account the general conditions (starting values) in Europe. In addition to Mannheim as a central European location, Lisbon was selected as the southern location and Helsinki as the northern location.

The annual differential costs were determined as the basis for the economic valuation. These result from the monetary recovery of heat in the winter, and the recovery of cold in summer. The expenses resulting from the electrical energy requirement, maintenance costs, debt service, etc. were deducted from this amount. The results for the recovered heat are shown in **Table 1**.

Table 1. Average thermal work of the examined designs.

		Day h	night h	total	Heat	colth	heat HR	colth HR	North-South	operating
		h/a	h/a	h/a	kWh	kWh	kWh	kWh	factor	time factor
North	Helsinki	2,346		2,346	173,111	2,943	117,478	104	4.10	1.00
4865										
Middle	Mannheim	2,346		2,346	117,567	10,495	80,310	992	2.80	1.00
4829										
South	Lisbon	2,346		2,346	44,106	26,772	28,665	3,336	1.00	1.00
4698	units							11.6%		
		Day h	night h	total	Heat	colth	heat HR	colth HR	North-South	operating
		h/a	h/a	h/a	kWh	kWh	kWh	kWh	factor	time factor
North	Helsinki	3,754		5,005	330,324	4,913	236,385	177	3.95	2.01
4875										
Middle	Mannheim	3,754	1,251	5,005	226,817	17,460	163,926	1,645	2.74	2.04
4822										
South	Lisbon	3,754	1,251	5,005	86,003	44,496	59,786	5,534	1.00	2.09
4774	units							9.3%		
		Day h	night h	total	Heat	colth	heat HR	colth HR	North-South	operating
		h/a	h/a	h/a	kWh	kWh	kWh	kWh	factor	time factor
North	Helsinki	4,380	4,380	8,760	510,922	6,221	389,513	230	3.74	3.32
4885										
Middle	Mannheim	4,380	4,380	8,760	359,659	22,274	277,637	2,077	2.67	3.46
4857										
South	Lisbon	4,380	4,380	8,760	139,423	57,753	104,018	7,058	1.00	3.63
4765	units							6.8%		
		Day h	night h	total	Heat	colth	heat HR	colth HR		
		h/a	h/a	h/a	kWh	kWh	kWh	kWh		
project values		3,972	1,902	5,712	300,596	17,462	219,780	1,865		
4885	units									

While in Lisbon heat is recovered on average W = 28,665 kWh/a for a run time of around L = 2,350 h/a, in Helsinki this is W = 117,478 kWh/a for the same run time (see **Figure 1**).

If the plants examined are operated around the clock, the HR in Lisbon W = 104,018 kWh/a and in Helsinki W = 389,513 kWh/a. This corresponds to about a factor of four between northern and southern Europe. In Mannheim, around 2.7 times the heat could be recovered compared to the south. It also becomes apparent that approximately 3.5 times as much energy can be recovered in a 24-hour operation as in the 9-hour operation (L = 2,350 h/a).

The average temperature transfer rate of all designs was Φ = 71.9% with a standard deviation of s = 5.8 percentage points during the period under study.

By contrast, the recovery of sensitive cold is very low (see **Figure 2**) and even in Lisbon there is a maximum of 11.6% heat energy (see **Figure 1**). In Helsinki, the share of cold recovery is irrelevant, as it only accounts for 0.1% of the heat energy.

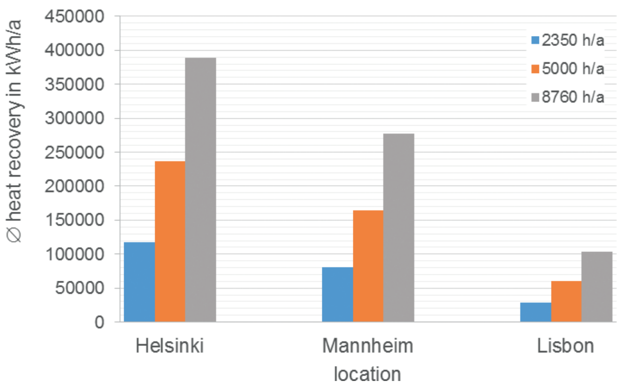

Figure 1. Average heat recovery of the plants in kWh/a

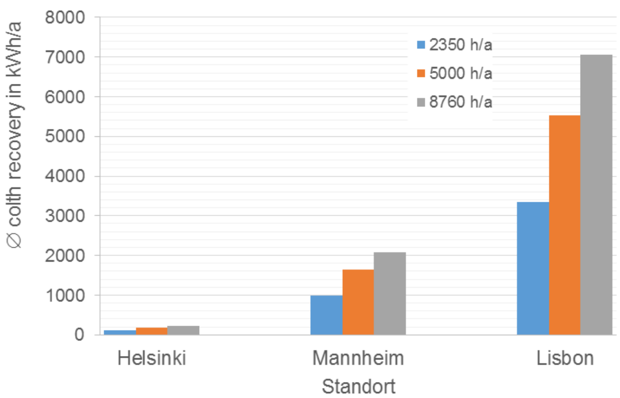

Figure 2. Average cold recovery of the plants in kWh/a.

Based on the actual project data (mostly in Germany), the average run time of the plants was L = 5,712 h/a with an average recovery of W = 219,780 kWh/a.

If the monetary effect of the HR is calculated, the results are shown in **Table 2**. This was calculated with a price of 0.08 €/kWh for heat, an electricity price of 0.17 €/kWh, and a price of 0.05 €/kWh for cooling energy. An imputed interest rate of 3%/a was applied. The rate of price increase was 2%/a. The useful life of the HR was selected with 15 years. The utilisation of the HR unit during daytime hours is assumed to be 100% of the target air volume, and at night hours 50%. The investment costs of the HR systems in the study are averaged at I = €25,100.

In a 9-hour operation (around L = 2,350 h/a), the plants examined in Lisbon would generate an average loss of K = −1,737 €/a at an efficiency of 71.9%. Overall, 93.7% of all investments in Southern Europe would be uneconomical (negative differential costs per year), while a profit of K = 5,233 €/a would be generated in Northern Europe for the same term. In Helsinki, therefore, only 2.1% of specific installations would generate project-specific losses.

In the 24-hour operation, an average profit of K = 2,741 €/a would even be generated in Lisbon. However, even with this run time, 7.4% of the examined plants would still generate a loss. In Helsinki, however, it would be possible to generate a profit of K = 25,171 €/a with the same investments (see also **Figure 3**). Under these conditions, none of the plants examined would be uneconomical at this location.

If all plants were economically optimized at a constant design speed, a higher profit would be generated, which could avoid a loss on average for all plants.

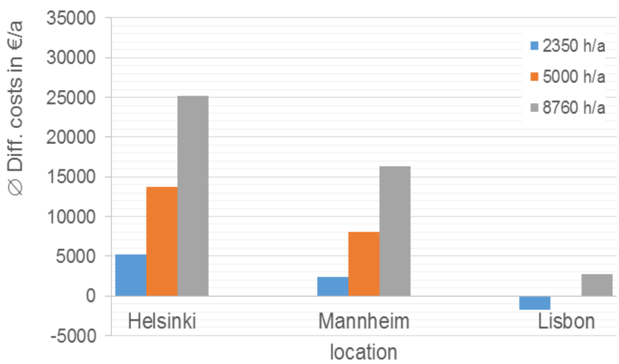

Figure 3. Annual differential costs under design conditions.

However, the systems with average transmission degrees from Φ = 33.4% in Lisbon to Φ = 65.2% in Helsinki would then have to be produced, i. e. with significantly lower transmission rates than the actual, resulting average and undifferentiated Φ = 71.9% of the systems investigated in this field study. In Mannheim, the optimum transmission degree under these conditions would be Φ = 58.3%.

With a run time of L = 5,000 h/a, transmission degrees of Φ = 47.4% in Lisbon and Φ = 72.3% in Helsinki would be required. Mannheim then requires a transmission degree of Φ = 67.2% at unchanged flow velocity.

Even during the 24-hour operation (L = 8,760 h/a), transmission degrees of Φ = 56.9% (Lisbon) and Φ = 76.8% (Helsinki), as well as Φ = 72.8% (Mannheim) would make sense. A 2.8% higher profit could be generated in Helsinki, while a 43.6% higher profit could be achieved in Lisbon.

If a multidimensional optimization is carried out at a flow velocity of about w = 1 m/s, significantly higher gains could be achieved (see **Figure 4**). For a 9-hour operation in Mannheim, for example, the annual differential costs could be increased to € 4,097/a (+ 76.2%) with an average of K = € 2,325/a.

A significant increase in yields would also be possible in 24-hour operation, which could be +22.3% in Helsinki (K = 25,171 €/a to K = 30,774 €/a) and +119.1% in Lisbon (K = 2,741 €/a to K = 6,005 €/a) (see **Table 2**).

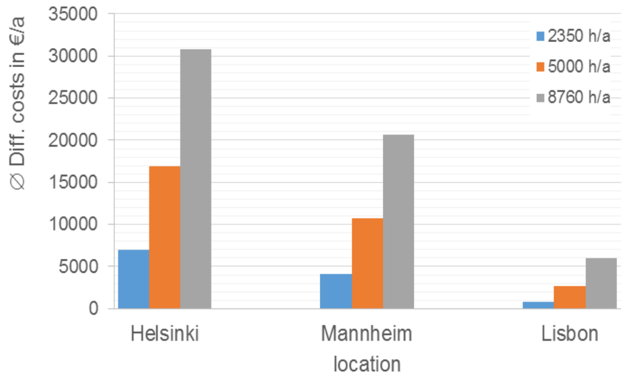

Figure 4. Annual differential costs after 3D optimization.

Table 2. Monetary results (differential costs average values) of the economic efficiency calculation.

		Diff. Costs	1D Opt.	HRE	Delta 1D	Delta 1D	3D Opt.	HRE	Delta 3D	Delta 3D	3D w
2.350 h/a		€/a	€/a	%	€/a	%	€/a	%	€/a		m/s
North	Helsinki	5,233	5,699	65.2	464	8.9%	6,944	71.0	1,711	32.7%	1.01
			s =	7.96			s =	9.18			0.09
Middle	Mannheim	2,325	3,165	58.3	832	35.8%	4,097	65.3	1,772	76.2%	1.01
			s =	9.27			s =	10.64			0.09
South	Lisbon	-1,737	447	33.4	2,130	-122.6%	773	44.7	2,510	-144.5%	1.03
			s =	14.30			s =	14.60		s =	0.12
		Diff. Costs	1D Opt.	HRE	Delta 1D	Delta 1D	3D Opt.	HRE	Delta 3D	Delta 3D	3D w
5.000 h/a		€/a	€/a	%	€/a		€/a	%	€/a		m/s
North	Helsinki	13,676	13,955	72.3	276	2.0%	16,945	78.7	3,269	23.9%	1.00
			s =	5.98			s =	6.91			0.07
Middle	Mannheim	8,014	8,401	67.2	387	4.8%	10,762	74.8	2,748	34.3%	0.99
			s =	6.76			s =	7.98			0.06
South	Lisbon	-135	1,628	47.4	1,745	-1292.5%	2,725	59.7	2,860	-2118.2%	0.99
			s =	10.07			s =	11.85		s =	0.06
		Diff. Costs	1D Opt.	HRE	Delta 1D	Delta 1D	3D Opt.	HRE	Delta 3D	Delta 3D	3D w
8.760 h/a		€/a	€/a	%	€/a		€/a	%	€/a		m/s
North	Helsinki	25,171	25,865	76.8	693	2.8%	30,774	82.8	5,603	22.3%	1.01
			s =	5.02			s =	5.84			0.07
Middle	Mannheim	16,326	16,604	72.8	277	1.7%	20,616	79.9	4,290	26.3%	0.99
			s =	5.57			s =	6.53			0.06
South	Lisbon	2,741	3,949	56.9	1,196	43.6%	6,005	68.3	3,264	119.1%	0.98
			s =	8.37			s =	9.77		s =	0.04
		Diff. Costs	1D Opt.	HRE	Delta 1D	Delta 1D	3D Opt.	HRE	Delta 3D	Delta 3D	3D w
5.712 h/a		€/a	€/a	%	€/a		€/a	%	€/a		m/s
project values		16,255	16,902	71.8	636	3.9%	19,873	77.4	3,617	22.3%	1.02
			s =	8.42			s =	8.80		s =	0.09

However, even in this case, the optimal transmission degree is not identical in the different locations. While in Lisbon max. Φ = 68.3% makes sense, in Helsinki this is Φ = 82.8%. In Mannheim, the maximum transmission degree under these conditions is Φ = 79.9%. In the 9-hour operation, the maximum meaningful transmission degrees are reduced to a maximum of Φ = 71.0% in Helsinki, Φ = 65.3% in Mannheim and Φ = 44.7% in Lisbon. However, all transmission degrees can only be used sensibly if the flow velocity for design is around w = 1 m/s in order to minimize pressure losses.

In Germany, in contrast to the chosen framework conditions, +22.3% higher yield could be achieved in accordance with the project-specific, individual values (cf. **Table 2** bottom line). The higher value is due to the fact that higher specific energy prices were expected in the specific projects.

Reference points

If the EU1253/2014 reference values, which are to enter into force from 2020 as part of the revision of the Ecodesign regulation are applied today, the result will be as follows (see **Table 3** and **Table 4**).

On average, the HR would have to be twice as large in its transmission units as it has been in recent years.

In Helsinki, a 9-hour operation could no longer generate a profit of K = 5,233 €/a compared to the situation in recent years, with a yield of only of K = 2,609 €/a (see **Table 4**).

In Lisbon, instead of the loss of K = –1,797 €/a already incurred today, a significantly higher loss of K = –5,566 €/a would be the result. And in Mannheim a loss of K = –789 €/a would result instead of an average profit of K = 2,325 €/a. Even with a 24-hour operation (L = 8,760 h/a), the plants examined in Lisbon would cause an average loss of K = –1,905 €/a.

Figure 5. Annual differential costs under various conditions for Helsinki.

Even under the current conditions, an average profit of K = 2,741 €/a would still be possible in Lisbon. By comparison, the same investments in Helsinki would generate an average profit of K = 25,171 €/a (in Mannheim K = 16,326 €/a).

Figure 5 and **Figure 6** also show the annual savings for the Helsinki and Lisbon locations with different run times. Even at an optimal flow velocity of about w = 1 m/s, the reference values of the EU1253/2014 would cause lower yields. Although the average transmission degrees would be between Φ = 83% and Φ = 84%, all yields would be lower than in the multi-dimensionally calculated optimum. **Figure 7** shows the corresponding result for Mannheim.

Even in Helsinki, 24-hour operation would reduce the yields from K = 30,744 €/a to K = 30,505 €/a, i.e. by –0.9%. In Lisbon, on the other hand, a 9-hour operation (L = 2,350 h/a) would turn the remaining small profit of K = 773 €/a into a significant loss of K = –2,877 €/a.

Table 3. Necessary change of the heat exchanger index Number of transfer units (NTU) under reference conditions.

		NTU actual	NTU target	NTU Factor target / actual
North	Helsinki	2.69	5.08	2.04
	s =	0.90	0.80	0.79
Middle	Mannheim	2.69	5.08	2.04
	s =	0.90	0.80	0.79
South	Lisbon	2.69	5.09	2.05
	s =	0.90	0.80	0.81

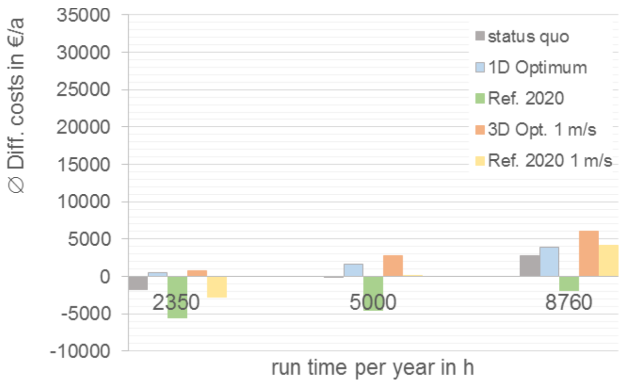

Figure 6. Annual differential costs for Lisbon under different conditions.

Table 4. Monetary results of the economic efficiency calculation under reference conditions.

	run time	Diff. costs K Actual	Diff. costs K Opt.	Diff. costs K Ref. 2020	Diff. costs K 3D Opt.	Diff. costs K Ref. 2020 (1 m/s)
	h/a	€/a	€/a	€/a	€/a	€/a
Helsinki	2,350	5,233	5,699	2,609	6,944	5,399
North	5,000	13,676	13,955	11,476	16,945	16,230
	8,760	25,171	25,865	24,186	30,774	30,505
Mannheim	2,350	2,325	3,165	-789	4,097	1,984
Middle	5,000	8,014	8,401	4,926	10,762	9,612
	8,760	16,326	16,604	13,878	20,616	20,041
Lisbon	2,350	-1,737	447	-5,566	773	-2,827
South	5,000	-135	1,628	-4,537	2,725	87
	8,760	2,741	3,949	-1,905	6,005	4,106

Table 5. Possible transmission degrees of the HR and their average annual differential costs.

		3D-Optimum	Ø Diff.- costs	ΔP average
		%	€/a	Pa
Helsinki	2,350 h/a	71	6,944	61
North	5,000 h/a	79	16,945	91
	8,760 h/a	83	30,774	119
		%	€/a	Pa
Mannheim	2,350 h/a	65	4,097	47
Middle	5,000 h/a	75	10,762	71
	8,760 h/a	80	20,616	96
		%	€/a	Pa
Lisbon	2,350 h/a	45	773	21
South	5,000 h/a	60	2,725	35
	8,760 h/a	68	6,005	51

Figure 7. Annual differential costs for Mannheim under various conditions.

Evaluation

It should be noted that the HR has successfully established itself in Europe. However, if the EU 1253/2014 reference values are actually converted into applicable law as of 2020, the recovered heat output will increase by around 15%, but the amount of equipment required will increase by a factor of around 2.

This development is not economic, as the average yields of the HR will fall across Europe. This has been clearly demonstrated by the field study at the individual case level at around 4,800 plants examined.

Yields will fall significantly in all cases. In the quintessence of the findings, the application of the reference values in Europe from 2020 will not make any investment in Europe more economical than it is today.

It is to be hoped that the European Commission will also recognise and correct this design error in the regulation. It makes sense that the revision of the regulation must at least take into account both the location of installation of the HR and its run time.

If the results of the field study are reduced to the transmission degree, the following values could be useful for minimum transmission rates and maximum pressure losses at the HR (see **Table 5**).

The air velocity in the device should then be about w = 1 m/s. Lower air speeds are hardly sensible any more, as the systems should also to operate at partial load. At an air velocity of w = 1 m/s a partial load operation up to about w = 0.4 m/s would be possible. ■

LIST OF ABBREVIATIONS

AHU	Air handling unit
ΔP	Differential pressure loss [Pa]
I	Investments [€]
K	annual differential costs [€/a]
L	Runtime [h/a]
NTU	Number of Transfer units [./.]
Φ	Temperature transfer coefficient or heat recovery efficiency [%]
HR	Heat recovery
s	Standard deviation
w	Flow velocity at the narrowest cross section in [m/s]
W	Thermal energy [kWh/a]